BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: Preliminary Results of an Attractive Earth-Venus-Mercury Mission in 1978 - Case 103

DATE: October 9, 1968

FROM: A. A. VanderVeen

ABSTRACT

An attractive Earth-Venus-Mercury opportunity in 1978 is identified. Because of an energy constraint applied to previous investigations of such missions during the 1970's and through misinterpretation of the reported findings, no suitable Mercury missions were thought to exist during the late 1970's.

A preliminary description of the mission characteristics is presented along with the underlying reasons for the lack of information previously available.

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MEMORANDUM FOR FILE

Introduction

The purpose of this preliminary memorandum is to present the salient features of an attractive Venus-swingby-to-Mercury mission that is available in mid-1978. The significance of the results presented here lies in the fact that it has been popularly believed that such missions in the 1970's were limited to two opportunities--1970 and 1973--after which none were available until the next decade. This belief was due to the fact that previous investigations of this opportunity and others in the 1970's were limited to trajectories with a launch energy of $C_3 = 21\ km^2/sec^2$ or less. Consequently, Mercury missions in the late 1970's could not be included in the unmanned planetary exploration program. A more detailed reporting of the 1978 launch opportunity will be forthcoming shortly.

General Features

Specific characteristics of a minimum energy trajectory are given in Table 1 and general features of the opportunity are pointed out below.

- 50-day launch window (7/11/78-8/30/88) with launch energies between $C_3 = 32.7$ and $35\ km^2/sec^2$
- Injection velocities below 15,400 fps or 4.7 km/sec from 100 n.m. earth orbit.
- Adequate Venus passage distances (1.5 to 2.5 Venusian radii of closest approach)
- Low inclination outbound legs ($\sim -2°$) with $-29°$ declinations.
- Relatively low Mercury arrival velocities (less than 30,000 fps retro ΔV to 250 n.m. circular orbit).
- 142-day trip time to Mercury, 86-day 1st leg.

TABLE 1

Minimum-Energy 1978 Earth-Venus-Mercury
Mission Characteristics

	Date		V_∞	ΔV
	Julian	Calendar	(emos)	(ft/sec)
Earth	244 3732	8-12-78	.1922	15,120*
Depart			$C_3 = 32.7$ (km^2/sec^2)	
Venus	244 3818	11-6-78	.4100	0
Passage				$V_p = 45{,}750$ $R_p = 2.323$
Mercury	244 3874	1-1-79	.3527	27,740**

*100 n.m. circular Earth orbit

**250 n.m. circular Mercury orbit

The trajectories cited above represent an increase of from 1600 to 1800 fps in injection velocity from a low altitude circular orbit over the bounding value of 13,600 fps associated with a 21 km^2/sec^2 C_3 launch energy constraint. The effect of this constraint is compared with an energy constraint equal to the maximum required by the trajectories available during the 50-day 1978 launch period by means of the payload capabilities of several vehicle configurations proposed for use in 1978. These payload variations (Table 2) reflect the increased flexibility in mission planning thought to be possible since 1966 when Sturms' constraints were justified.

TABLE 2

Payload Capabilities of Several
Vehicle Configurations

Vehicle	Payload (lbs)*	
	C_3=21 km^2/sec^2 V_c=3.9 fps	C_3=35 km^2/sec^2 V_c=41.1 fps
SLV-3C Centaur	1300	550
SLV-3X Centaur	2800	1900
Titan 3D Centaur	8500	6700
Titan Agena	4600	3400
SLV-3 Centaur w/Burner II	1900	1450
SLV-3X Centaur w/Burner II	3200	2300

NOTE: If the SLV-3X is developed, the SLV-3C would be eliminated from the stable of available vehicles.

*Through personal communication with B. C. Lam, NASA/SV.

Trajectory Analysis

Examination of the synodic periods of Venus and Mercury indicates that a given planetary configuration should repeat itself after eight years allowing for angular deviations of Mercury with respect to Earth of about 47°. While this is a large deviation, it should be pointed out that twenty-five Mercury-Earth and Twenty Mercury-Venus synodic periods occur during the eight year period which comprises five Venus-Earth synodic periods. Since synodic periods are based on mean orbital velocities, it was expected that larger deviations yet would become evident because of Mercury's high eccentricity and inclination.

Sturms and Cutting's 1970 Earth-Venus-Mercury trajectory data were readily available, so eight years were added to the planetary encounter dates of that mission and a solution for a trajectory in 1978 was obtained by computer means. Venus impact conditions were found to exist on the first run, but when the Earth departure and Mercury arrival dates were adjusted during subsequent runs, adequate Venus passage clearances were obtained at a modest increase in launch energy over a wide launch period.

Background

A brief investigation was made to determine why data was unavailable concerning the 1978 opportunity, and a survey of the literature was undertaken. In the early 1960's Clarke (1) investigated direct interplanetary trajectories to several planets, including two trips to Mercury (1967, 1968). Minovitch (2) explored the Venus swingby mode for Mercury missions for the 1965 to 1975 time period and showed that significant savings in launch energy and Mercury arrival speeds could be achieved over the direct mode. Cutting and Sturms (3) investigated Minovitch's 1970 low-energy mission in detail, and because of the interest it aroused, Sturms (4) undertook and in-depth investigation of Venus-swingby-to-Mercury missions in the 1970's. He subsequently made a very detailed analysis of a specific mission during the 1973 opportunity (5). Wallace (6) analyzed the 1975 opportunity using an impulsive flyby of Venus.

The period from 1980 to 2000 was explored in detail by Manning (7) for a variety of mission modes to Mercury including powered and ballistic swingbys of Venus. Other published references to Mercury missions are usually based on the trajectories investigated by Sturms.

Sturms' analysis of Earth-Venus-Mercury missions in the 1970's was very thorough and is well documented. He explicitly stated the constraints he imposed on the investigation, namely that (a) an energy match had to exist between inbound and outbound trajectories at Venus, (b) that the flyby hyperbola at Venus clear the planet's surface, and (c) that the launch energy of the outbound leg was less than 21 km^2/sec^2 (C_3). Within the context of these constraints no trajectories were found to exist for the 1977 and 1978 opportunities, and the statement was made that, "...any consideration to perform an Earth-Venus-Mercury mission must be limited to 1970 or 1973, or else postponed to the 80's."

Personal communications with Sturms reveals the following reasoning for imposing the 21 km^2/sec^2 energy constraint: This value represents a sizeable payload capability (1300 lbs) using the Atlas-Centaur launch vehicle. Greater energy trajectories would reduce the payload capability to the point where spacecraft and experiment weights would be unacceptably low as judged by mission studies performed at that time. In order to increase the payload for higher energy trajectories, launch vehicles would be required which were outside the framework of then-current planning; and if a new launch vehicle were to be developed for this class of missions, it would probably be large enough to accommodate greatly increased C_3 values (to, say, 50) and then the direct, rather than Venus swingby mode, could be used for Mercury missions.

The root of the problem, as seen by the writer lies mainly in the fact that the results of Sturms' analysis were not interpreted by the space community in the context of the specific constraints of the investigation.

Conclusions

The 1978 opportunity for Venus-swingby-to-Mercury missions is attractive from the standpoint of trajectory analysis, and in the light of increased vehicle payload flexibility the study of these mission opportunities in the 1970's should be reinvestigated.

A. A. VanderVeen

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Attachments
  References

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